(54) **VOLTAGE REGULATION OF HIGH VOLTAGE DIRECT CURRENT SYSTEMS**

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RÉGULATION DE TENSION DE SYSTÈMES À COURANT CONTINU HAUTE TENSION

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Description

CROSS-REFERENCE TO RELATED APPLICATIONS

BACKGROUND

[0001] For various reasons, aerial and ground vehicles increasingly use electricity to control operations and provide various services. For example, different electrical systems are being added to the vehicles to provide additional features. Also, previously non-electrical systems are being electrified, like using hybrid-electric propulsion systems instead of traditional propulsion systems. Vehicles may include power generators to provide at least a portion of the power used by the various systems.

[0002] Further, as aerial and ground vehicles evolve, particularly over the past few decades, so has the demand for electrical systems that enable the functionality of the vehicles. Particularly for aerial and ground vehicles, electrification has resulted in a demand for systems that can produce high voltage direct current (HVDC) at high power levels (i.e., 100 kW or greater). Documents cited during prosecution include US 2009/174188 A1; EP 3 772 816 A1; US 2011/133703 A1; "Excitation System Technologies for Wound-Field Synchronous Machines: Survey of Solutions and Evolving Trends" by Kristiansen et al.; and US 2012/106007 A1.

[0003] US 2009/174188 A1 discloses a three-core synchronous design, wherein a rectifier in the form of a main IGBT/ diode bridge is connected after the generator. In this case, the POR is always the DC voltage after the rectifier, but an AC voltage loop present in the control scheme is mentioned as playing an important role during load transients for keeping the DC voltage of the POR in a desired range.

[0004] EP 3 772 816 A1 considers the possibility of using either the AC voltage at the output of the generator (input of the rectifier) as POR, or the DC voltage at the output of the rectifier as POR, but in different embodiments.

[0005] US 2011/106007 A1 discloses a POR selector to switch the regulation input, but does it among the DC voltage output of two rectifiers, each of them after the generator, and the switching is based on a failure.

SUMMARY

[0006] Aspects and preferred embodiments of the invention are defined in the appended claims. Systems and methods for voltage regulation of high voltage direct current systems are provided. Disclosed herein is a system includes a generator that generates alternating current (AC) voltage. The system further includes a power converter that converts the AC voltage into regulated direct current (DC) voltage. Also, the system includes a voltage regulator. The voltage regulator includes an AC voltage regulator that regulates the AC voltage generated by the generator. Also, the voltage regulator includes a DC volt-age regulator that regulates the DC voltage produced by the power converter. Moreover, the voltage regulator includes a regulator selector that selectively activates one of the AC voltage regulator and the DC voltage regulator based on a current from the power converter and at least one of a voltage of the generator and a voltage of the power converter.

DRAWINGS

[0007] Drawings accompany this description and depict only examples which should not be considered limiting in scope.

FIG. 1 is a block diagram illustrating a typical system providing alternating current voltage regulation described herein;
FIG. 2 is a block diagram illustrating a system for voltage regulation of a high voltage direct current (DC) system according to the present disclosure:
FIG. 3 is a schematic diagram illustrating a system for voltage regulation of a high voltage DC system according to the present disclosure:
FIG. 4 is a diagram of an algorithm for providing voltage regulation for high voltage DC systems according to the present disclosure; and
FIG. 5 is a flowchart diagram of a method for providing voltage regulation for high voltage DC systems according to the present disclosure.

[0008] Under common practice, the various described features are not drawn to scale but are drawn to emphasize specific features relevant to the examples.

DETAILED DESCRIPTION

[0009] In the following detailed description, reference is made to the accompanying drawings that form a part of the present description and in which is shown, through illustration, specific examples. However, since the scope of the present invention is defined by the appended claims, it is to be understood that these and other examples may be used and that logical, mechanical, and electrical changes may be made, wherein the examples and their changes are covered by the present invention only if they do not contradict the appended claims (i.e. if they comprise at least all features of at least one of the independent claims).

[0010] The present disclosure provides systems and methods for voltage regulation of high voltage direct current (HVDC) systems. Power systems may produce direct current (DC) electrical power by converting alternating current (AC) electrical power generated by an AC generator. The present system includes a DC voltage regulator for regulating the voltage of the DC electrical power and an AC voltage regulator for regulating the voltage of the AC electrical power. A regulator selector determines whether to use the DC voltage regulator or the

AC voltage regulator by monitoring the voltage of the AC electrical power and the HVDC electrical power. As used herein, the term "high voltage direct current" or "HVDC" means a direct current (DC) potential difference of 270 VDC or greater. Typically, the regulator selector identifies the DC voltage as the point of regulation (POR), namely DC voltage regulator, and selects the AC voltage as the POR, namely AC voltage regulator, based on monitoring HVDC bus voltages and HVDC bus currents. Switching to the AC voltage regulator from the DC voltage regulator based on monitoring HVDC bus voltages and currents stabilizes the generator terminal voltage without oscillations, improves AC line to line peak voltage during the no-load/light load conditions, and improves voltage transients during load-on.

[0011] FIG. 1 is a block diagram illustrating a typical implementation of a generator system 101. As shown, the generator system 101 may be a brushless AC motor/generator. The generator system 101 may include a permanent magnet generator (PMG) 105, an exciter 107, a main generator 111, a generator control unit (GCU) 127, and one or more rectifier assemblies 109. A generator system, such as that shown as generator system 101, may operate as a starter generator for a gas turbine engine in aircraft, space, marine, land, or other vehicle-related applications that use gas turbine engines. Also, the generator system 101 may provide electrical power for various other systems found on vehicles or other stationary devices. Some aircraft applications use gas turbine engines for propulsion (e.g., the aircraft's main engines) and/or for power (e.g., the auxiliary power unit (APU)).

[0012] When the generator system 101 operates, a shaft 103 rotates the rotor of the PMG 105, the exciter rotor 107, and the main generator rotor 111. In the depicted example, the shaft 103 rotates the PMG 105, the exciter rotor 107, and the main generator rotor 111 along a single axis at the same rotational speed. However, in other embodiments, the PMG 105 may rotate along a different axis with a different rotor. Moreover, the relative positioning of the PMG 105, the exciter 107, and the main generator 111 can be modified in relation to one another.

[0013] As illustrated, as the shaft 103 rotates, the PMG 105 generates and supplies PMG AC power 113 to the GCU 127. The GCU 127 may include a rectifier 125 that receives the PMG AC power 113 from the PMG 105 and converts the PMG AC power 113 to DC power. When a PMG 105 is not included in the generator system 101, a separate DC power input 155 can function as a DC power source. The GCU 127 may include a DC controller 123 that is controlled by a controller 121. The GCU 127 may direct the DC controller 123 to provide controllable DC power 115 to a stator of the exciter 107. As the shaft 103 rotates the exciter 107, the exciter 107 may supply AC power to the rectifier assemblies 109. The output from the rectifier assemblies 109 is DC power supplied to power the main generator 111, where the main generator 111 outputs AC power.

[0014] During operation, the generator system 101 may output three-phase AC power from the main generator 111. One or more generator output leads 117 may supply the generated AC power to one or more loads 119. As used herein, a load in the one or more loads 119 refers to a system or device that uses electrical power at various frequencies and/or voltages produced by the generator system 101. The GCU 127 can regulate the power output based upon monitoring the voltage and current generated by the main generator 111 through the generator output leads 117 and comparing the voltage and current against a reference voltage 129. The GCU 127 may regulate the AC voltage produced by the main generator 111 at a constant value when subjected to one or more loads 119 or speed variations. When regulating the AC voltage, the GCU 127 may measure the voltages and currents at the AC POR 131 (at the output of the main generator 111) as feedback, and the GCU 127 may use the measurements to control excitation voltages for the main generator 111.

[0015] In embodiments of the present disclosure, a power converter converts the AC voltage, generated by systems such as the generator system 101 shown in FIG. 1, to a DC voltage. Systems having a typical GCU (like GCU 127) may not regulate the voltage correctly. For example, some typical systems may generate HVDC with a three-phase AC generator (such as the generator system 101) with diode rectifiers. Other typical systems may generate HVDC with a multi-phase AC generator and diode rectifiers. These generator topologies may be subject to certain problems with DC POR. One problem may include generator voltage instability during voltage build-up with DC POR under no-load conditions. Another problem with DC POR may include voltage overshoot during full load to no load transients, full load to light load transients, or both.

[0016] When a system experiences generator voltage instability with DC POR during voltage buildup under no-load conditions, a generator terminal voltage becomes unstable if the DC POR voltage is higher than a DC POR reference voltage. As the system is under a no-load condition, DC bus capacitors may remain charged and keep the voltage at a high value, and the generator terminal voltage may reduce continuously because of action by a generator control unit. During this period, the diodes of a rectifier may be in reverse bias and cause voltage instability.

[0017] As stated above, a system may experience DC POR voltage overshoots during full-load to no-load or full-load to light-load transients. The transients caused by the removal or lightening of the load can lead to several issues. For example, when a load is suddenly removed, the DC POR voltage may instantly increase, leading to a DC bus overvoltage because of the load transient. In some examples, when a load is removed, the time to discharge the DC bus voltage to a normal voltage is extended because of DC bus capacitance. Extending the time to discharge can lead to the voltage exceeding volt-

age transient requirements defined in standards like the MIL-Std-704F or other stated design requirements. Additionally, if the DC bus capacitances are set to small values to meet voltage transient requirements, the DC bus overvoltage amplitude may exceed the overvoltage limit, and a system may experience DC overvoltage faults. Further, the terminal voltage of the generator may decrease because of the actions of a generator control unit, causing a system to be in an unstable state.

[0018] Embodiments of the present disclosure address generator voltage instability with a DC POR by monitoring AC power voltages and HVDC bus voltages and currents. For example, systems switch the POR from DC voltage regulation to AC voltage regulation based on the monitoring of the AC power voltages and the HVDC bus voltages. Systems may switch the POR from DC to AC voltage regulation upon detecting either no-load or a light-load during voltage buildup conditions or steady-state operation. Further, during load transients from full-load to no-load or light-load, the GCU may switch the POR to AC voltage regulation based on the monitoring of the HVDC bus voltages and currents. When the GCU switches the POR to AC voltage regulation, a GCU may regulate the generator voltage based on a defined reference voltage that monitors the AC voltages generated by the generator. Swapping the POR from the DC voltage regulation to AC voltage regulation stabilizes the generator terminal voltage without oscillations and improves the performance of the AC line-to-line peak voltage during no-load or light-load conditions and improves the voltage transient during load-on.

[0019] In certain embodiments, in addition to swapping the POR from DC voltage to the AC voltages, a generator system may address the transient response during load-off by detecting a load-off transient. When the system detects a load-off transient, the generator system may control a field dump resistor (FDR) and a dynamic break resistor (DBR). The GCU may include the FDR to increase the rate that field energy is dissipated when activated. Additionally, the DBR limits the DC bus overvoltage to bring it back to normal steady-state limits.

[0020] The generator system may control the DBR using DBR hardware in conjunction with the GCU. The DBR hardware and/or the GCU may detect an overvoltage and turn on the DBR during a load-off transient. For example, the DBR hardware initially controls the DBR using an overvoltage detection circuit during a load-off transient to limit a DC bus overvoltage. After the initial operation of the DBR hardware control, the GCU may control the operation of the DBR. The initial control of the DBR by the DBR hardware control may reduce the delay on the DBR operation when a load-off transient is detected.

[0021] In some embodiments, a DBR power rating may depend on the highest voltage limited by the DBR and on a DC bus capacitor. For example, to meet specific operational requirements (such as the MIL-Std-704f voltage transient requirement), the DC bus voltage should be below the DC voltage limit and should come back to steady-state limits within a specific time period from the instant a load-off transient begins. Once the DC bus voltage returns to steady-state, the DBR hardware or GCU may turn off the DBR. The size of the DBR may be proportional to the duration of the time used to come back from the load-off transient to steady-state. For example, a faster return to steady-state may permit a smaller DBR size. The reduction of DBR size may provide some advantages in certain applications. Effective control of the DBR allows for reducing a DC bus capacitor rating, permitting a reduction in capacitor size.

[0022] In some embodiments, either the DBR hardware or the GCU coordinates the operation of the DBR with the FDR to improve the control of the DC bus voltage. For example, during the operation of the DBR, the FDR may be active, and the pulse width modulation (PWM) of the exciter may be disabled to permit improved control of the DC bus voltage. After the operation of the DBR completes, the FDR can be disabled, and the PWM of the exciter may enter an active state.

[0023] Therefore, embodiments described herein are drawn toward systems and methods that enable the regulation of HVDC produced by generators. In particular, systems and methods described herein may help the regulation of the HVDC to achieve defined industry standards.

[0024] FIG. 2 is a block diagram of a system 200 that switches the POR between a DC voltage regulator and an AC voltage regulator based on the monitoring of HVDC bus voltages and HVDC bus currents. The system 200 includes a generator 201 and a power converter 203 for converting AC power produced by the generator 201 into DC power. The power converter 203 may be a rectifier, a series of rectifiers, or other suitable device for converting AC power into DC power. The generator 201 may function similar to the generator system 101 described above in FIG. 1. For example, the generator 201 may be a multi-phase generator that produces AC power. In some embodiments, the generator 201 produces three-phase, six-phase, or other number of multi-phase AC power. Further, the generator 201 may include a PMG (such as PMG 105 in FIG. 1) that generates AC power, which is then converted to DC power for the operation of an exciter (such as exciter 107 in FIG. 1). Alternatively, the generator 201 may receive DC power through a DC power input 255.

[0025] In certain embodiments, the system 200 may provide DC power to other systems (load 213) coupled to the generator 201. To provide the DC power, the generator 201 provides the generated AC power to a power converter 203, the power converter 203 converts the AC power into DC power, and provides the DC power through a DC bus 212 for use by a load 213. The load 213 may function similar to the one or more loads 119 described above in FIG. 1. The DC bus 212 may have a DC bus capacitor 215 that acts as a capacitance bank for the distribution of DC power to the load 213.

[0026] In exemplary embodiments, the system 200 in-

cludes a voltage regulator 205 that functions similar to the GCU 127 in FIG. 1. In contrast to the GCU 127, the voltage regulator 205 includes a regulator selector 223 that selects one of a DC voltage regulator and an AC voltage regulator based on DC and AC power measurements. The regulator selector 223 may implement logic that determines whether to switch to AC voltage regulation or DC voltage regulation based on the DC and AC power measurements. The regulator selector 223 may be implemented using hardware, software, or a combination of hardware and software. As the regulator selector 223 can be implemented with software, the voltage regulator 205 may include a processor that executes some instructions when selecting one of the AC or DC voltage regulation.

[0027]   In some examples, the voltage regulator 205 may manage separate DC and AC voltage regulators that are part of the voltage regulator 205. Alternatively, the voltage regulator 205 may receive input signals for both the DC and AC voltage and be a single device that selectively regulates generator 201 (AC voltage) and power converter 203 (DC voltage). In some exemplary implementations, the voltage regulator 205 may receive DC measurements 211 from the DC bus 212 and AC measurements 209 from the generator 201. The controlled excitation to the generator 201 may be represented by control signal 207. The DC measurements 211 may include the DC voltage and the DC current. Similarly, the AC measurements may include the AC voltage and the AC current. During regular operation, the regulator selector 223 may select the DC voltage regulator to functions as the point of regulation for the system 200. As used herein, regular operation refers to the operation of the system 200, when the generator 201 is providing power to a load 213. The regulator selector 223 may monitor the DC and AC measurements to detect no-load, light-load, and transient conditions, e.g., not "regular operation." When the regulator selector 223 detects the no-load/light-load during voltage buildup or steady-state operation, the regulator selector 223 may switch the POR from the DC voltage regulation to the AC voltage regulation. Additionally, the voltage regulator 205 may switch the POR to AC voltage regulation during load transients.

[0028]   In additional embodiments, the system 200 may include a dynamic break resistor (DBR) unit 217. The DBR unit 217 may include a DBR 216 and an insulated gate bipolar transistor (IGBT) 218. The DBR 216 may be turned on by the IGBT 218 that is controlled by hardware or the voltage regulator under load off conditions. For example, the voltage regulator 205 may control the DBR unit 217 by sending DBR control signals 219 to the DBR unit 217. Additionally, the DBR hardware 218 may provide partial control of the DBR 216, where the DBR hardware control functions together with the voltage regulator 205 to control the operation of the DBR 216. As described above, the DBR unit 217 limits the DC bus overvoltage and brings the DC bus voltage back to steady-state. Additionally, as described above, the voltage regulator 205 may include an FDR 221, which increases the dissipation rate of field energy during load-off transients. Accordingly, the system 200 can overcome the generator voltage instability with the DC POR during voltage buildup under no-load conditions. Also, the system 200 can regulate DC voltage overshoot during full-load to either no-load or light-load transients.

[0029]   In some embodiments, the function of the voltage regulator 205 (for example the regulator selector 223) may be performed by hardware or through the execution of instructions performed by a processor that receives the various measurements from the system 200. When the voltage regulator 205 includes a processor, the processor may execute portions of the methods described in the present disclosure. For example, the processor and/or other computational devices used within the system 200 may be implemented using software, firmware, hardware, or an appropriate combination thereof. The processor and other computational devices may be supplemented by, or incorporated in, specially designed application-specific integrated circuits (ASICs) or field programmable gate arrays (FPGAs). The processors and other computational devices can also include or function with software programs, firmware, or other computer-readable instructions for carrying out various process tasks, calculations, and control functions used in the methods and systems described herein.

[0030]   The methods described herein may be implemented or controlled by computerexecutable instructions, such as program modules or components, executed by at least the processors or other computing devices. Generally, program modules include routines, programs, objects, data components, data structures, algorithms, and the like, which perform particular tasks or implement particular abstract data types.

[0031]   Instructions for carrying out the various process tasks, calculations, and generation of other data used in the operation of the methods described herein may be implemented in software, firmware, or other computer-readable instructions. These instructions are typically stored on appropriate computer program products that include computer-readable media used to store computer-readable instructions or data structures. The computer-readable media may store computer-readable instructions or data structures. Such a computer-readable medium may be available media that can be accessed by a general-purpose or special-purpose computer or processor, or any programmable logic device.

[0032]   Suitable computer-readable storage media may include, for example, non-volatile memory devices including semi-conductor memory devices such as Random Access Memory (RAM), Read Only Memory (ROM), Electrically Erasable Programmable ROM (EEPROM), or flash memory devices; magnetic disks such as internal hard disks or removable disks; optical storage devices such as compact discs (CDs), digital versatile discs (DVDs), Blu-ray discs; or any other media that can carry or store desired program code as computerexecutable

instructions or data structures.

[0033] FIG. 3 is a schematic diagram of a system 300 that switches the POR between DC voltage regulation and AC voltage regulation based on the monitoring of HVDC bus voltages and HVDC bus currents. The system 300 includes a generator system 301. The generator system 301 is similar to the generator system 101 regarding the generation of AC electrical power. However, the generator system 301 may generate six-phase or other number of multi-phase AC electrical power in contrast to the three-phase electrical power generated by the generator system 101 in FIG. 1.

[0034] To generate the AC electrical power, the generator system 301 includes a rotor 303 that rotates an exciter 307 in relation to an exciter stator 308. The exciter 307 may function similarly to the exciter 107 in FIG. 1. For example, the exciter 307 may generate three-phase AC electrical power provided to a rectifier assembly 309. The rectifier assembly 309 may function similarly to the rectifier assemblies 109. The rectifier assembly 309 provides DC electrical power for driving a generator rotor 310 that rotates in relation to a generator stator 311. The generator stator 311 may provide AC power as an output of the generator system 301.

[0035] In certain embodiments, the generator system 301 provides measurements of the AC generator voltage 331 and an AC generator current 333 to a GCU 325, which functions as an AC voltage regulator. Accordingly, the output of the generator system 301 may function as an input to the AC voltage regulator. The GCU 325 may also provide an excitation field to the exciter stator 308 to control the operation of the exciter 307. Alternatively, DC power can be received through a DC power input 355 to provide the excitation field to the exciter stator 308. In addition to providing the measurements of the AC generator voltage 331 and the AC generator current 333 to the GCU 325, the generator system 301 may also provide AC electrical power to a power converter 313, where the power converter 313 converts the AC voltage to DC voltage.

[0036] In exemplary embodiments, after the system 300 converts the AC voltage to DC voltage, the system 300 may provide the DC voltage to a load through a DC bus 349. The DC bus 349 may include a DC bus capacitor or capacitors 335 and 337 that function similar to the DC bus capacitor 215. Additionally, the DC bus 349 may provide measurements of the DC power to the GCU 325. For example, the DC bus 349 may provide a DC voltage measurement 341 and a DC current measurement 343 to the GCU 325. The GCU 325 may then provide DC power distribution control 345 to the DC bus 349 by controlling an output DC contactor (ODCC) 347. In some implementations, the GCU 325 may include the functionality of the regulator selector (such as the regulator selector 223 in FIG. 2) by selecting either the DC voltage regulation 353 or the AC voltage regulation 351. Additionally, the GCU 325 may also include the functionality for providing the DC voltage regulation 353 and AC volt-

age regulation 351. Alternatively, the GCU may coordinate the operation of separate devices that provide the DC voltage regulation 353 and the AC voltage regulation 351. DC voltage regulation 353 and the AC voltage regulation 351 can be implemented in the same physical unit.

[0037] As described above, the GCU 325 may operate in conjunction with a DBR and FDR to provided DC voltage regulation. FIG. 4 is a diagram illustrating a method for power regulation of the systems 200 and 300. As shown, the method 400 receives five inputs when regulating the voltage produced by systems such as the systems 200 and 300. For example, the method 400 receives a DC current 401, a DC voltage 403, an AC voltage 405, an AC current 407, and a DC field current 409. The DC current 401 and the DC voltage 403 are the current and voltage produced by the generator system provided by the system to potentially connected loads. The AC voltage 405 and the AC current 407 are the voltage and current provided by the generator in the generator system before conversion from AC to DC. The DC field current 409 may refer to a DC field current applied to the exciter stator to drive the operation of an exciter.

[0038] As shown, the method 400 receives the various inputs and determines how to regulate the voltage between a DC POR and an AC POR. For example, using the DC current 401, the method 400 proceeds at 411, where a load-off transient is detected. Also, using the DC voltage 403, the method 400 proceeds at 413, where DC voltage is fed back to facilitate the DC voltage regulation at the DC POR. For example, the DC voltage regulation may be provided to the GCU, which then regulates the DC voltage. The DC voltage and the outcome of the detection of the load-off transient may be provided to an AC POR or DC POR selection logic at 419.

[0039] In exemplary embodiments, the method 400 receives the AC voltage at 415, where the AC voltage is feed back for regulation. For example, when the AC voltage 405 is produced by a six-phase generator, the AC voltage 405 includes six voltage measurements. Accordingly, the method 400 may also calculate a composite value for the six voltage measurements. For example, at 417, the method 400 calculates a root-mean-square (RMS) value for the AC voltages 405. The RMS value 417 may also be provided to the AC voltage feedback 415, where the AC voltage feedback 415 uses the RMS value 417 for regulation of the AC voltage produced by the generator. The AC voltage feedback 415 may be additionally provided to the AC POR or DC POR selection logic 419.

[0040] In certain embodiments, the selection logic 419 uses the DC voltage, the detected load-off transient, and the AC voltage feedback to determine whether to regulate the DC voltage or the AC voltage. For example, the selection logic may monitor the AC voltages and the DC bus voltages. When the load-off transient is detected, the selection logic 419 determines that the POR should switch from the DC voltage regulator to the AC voltage regulator. For example, the selection logic 419 deter-

mines that there is no load or a light load during a voltage buildup condition and/or steady-state operation and that the GCU should change the POR from the DC voltage regulator to AC voltage regulator. By switching the POR from the DC voltage regulator to the AC voltage regulator, a generator terminal voltage may remain stable without oscillations and maintain a desired AC line-to-line peak voltage during no-load or light-load conditions while improving voltage transients during load-on conditions.

[0041] To deal with overshoot, the method 400 proceeds at 421 with controlling an FDR and a DBR. As discussed above, the FDR and DBR may be controlled partly by DBR hardware and partly by a GCU. For example, the FDR and DBR control may receive the output from the load-off transient detection and the feedback DC voltage. From the inputs, the FDR and DBR control may detect an overvoltage and turn on the DBR during a load-off transient. As described above, DBR hardware may include an overvoltage detection circuit during the load-off transient. After the initial operation of the DBR hardware control, the DBR control is taken over by the GCU. For example, after the initial operation of the DBR hardware control, the GCU can produce FDR commands 423 and DBR commands 425 to control the operation of both the FDR and the DBR.

[0042] In certain embodiments, the method 400 proceeds at 427, where a power limit, current limit, and average RMS measurements are calculated for the AC power measurements. For example, power limit, current limit, and average RMS measurements are calculated based on the AC current measurements, an RMS value for the AC current, and an RMS value for the AC voltage. The method 400 then proceeds at 431, where a logic selects a regulation loop. For example, using the calculated limits, the average RMS value, and the AC POR or DC POR selection, the system selects the feedback loop in either the AC POR or the DC POR to be regulated.

[0043] In exemplary embodiments, the method 400 proceeds at 435, where multiple inputs are provided for use by voltage and current proportional-integral (PI) controllers. For example, the voltage and current PI controllers may receive signals from the regulation loop selection logic, the FDR and DBR control, an average RMS current, and a measurement of the DC field current 409 from the exciter. Using the various inputs, the voltage and current PI controllers may provide a signal having a specific duty cycle 437 that drives the rotation of the generator. The voltage and current PI controllers can then control the voltage and current produced by the generator.

[0044] FIG. 5 is a flowchart diagram of a method 500 for activating either DC voltage regulation or AC voltage regulation for power produced by a generator. Method 500 proceeds at 501, where operating conditions of a power generator having an AC generator and a DC converter are monitored. The method 500 proceeds at 503, it is determined whether the power generator is regularly operating. As described above, the power generator is

regularly operating when providing DC power to a load as compared to light-load or no-load operation (or transitions between operative states). When it is determined that the power generator is regularly operating, the method 500 proceeds at 505, where DC voltage regulation is activated. Alternatively, when it is determined that the power generator is not regularly operating, the method 500 proceeds at 507, where AC voltage regulation is activated. Additionally, after activating either the DC voltage regulation or the AC voltage regulation, the method 500 returns to 501 to continue monitoring operating conditions.

Claims

1. A system (200) comprising;

> a generator (201) configured to generate alternating current, AC, voltage;
> a power converter (203) configured to convert the AC voltage into regulated direct current, DC, voltage; and
> a voltage regulator (205) configured to function as a generator control unit for the generator (201), the voltage regulator (205) comprising:

>> an AC voltage regulator (351) configured to regulate the AC voltage based on an AC output of the generator (201);
>> a DC voltage regulator (353) configured to regulate the DC voltage based on a DC output of the power converter (203); and
>> a regulator selector (223) configured to select the DC voltage regulator during regular operation in which the DC voltage is provided to a load (213), and to select the AC voltage regulator (351) when at least one of a current from the power converter (203) and a voltage of the power converter (203) indicate at least one of a no-load condition, a light-load condition, and a transient.

2. The system (200) of claim 1, wherein the regulator selector (223) is configured to select the AC voltage regulator (351) based on a detected no-load condition, wherein the regulator selector (223) is configured to detect the no-load condition based on monitoring the current from the power converter (203), wherein the voltage regulator (205) is configured to regulate the generator AC voltages to a defined reference voltage during a transition from a load-on condition to at least one of the no-load condition and a light load condition.

3. The system (200) of claim 1, wherein the voltage regulator (205) includes a field dump resistor (FDR) (221) and is configured to provide control of a dy-

namic break resistor (DBR) (216), wherein operation of the DBR (216) is additionally controlled by DBR hardware (218) and the DBR hardware (218) initially controls the operation of the DBR (217) upon detection of a load-off transient, wherein the control of the DBR (217) passes from the DBR hardware (218) to the voltage regulator (205).

4. The system (200) of claim 1, further comprising a high voltage DC bus (212), wherein the high voltage DC bus (212) is configured to provide the DC voltage for use by one or more loads (213).

5. The system (200) of claim 1, wherein the voltage regulator (205) is a generator control unit (325).

6. A method comprising:

monitoring operating conditions of a system (200) having a generator (201) that generates AC voltage and a power converter (203) that converts the AC voltage into regulated DC voltage;

determining whether the power generator (200) is regularly operating based on a current of the DC bus (212) and the DC voltage, wherein the power generator (200) is regularly operating when providing DC voltage to a load (213);

when determining that the power generator (200) is regularly operating, selecting DC voltage regulation to regulate the DC voltage based on a DC output of the power converter (203);

when determining that the power generator (200) is not regularly operating by identifying, based on at least one of a current from the power converter (203) and a voltage of the power converter (203), at least one of a no-load condition, a light-load condition, and a transient, selecting AC voltage regulation to regulate the AC voltage based on an AC output of the generator (201); and

controlling operation of the generator based on the selected voltage regulation.

7. The method of claim 6, wherein identifying the no-load condition is based on monitoring the current of the DC bus (212), wherein the AC voltage regulation regulates the value of the AC voltage to a defined reference voltage during a transition from a load-on condition to the no-load condition.

8. The method of claim 6, further comprising controlling operation of a field dump resistor (FDR) (221) and a dynamic break resistor (DBR) (216).

9. The method of claim 6, wherein a generator control unit (325) determines whether the power generator (200) is regularly operating.

Patentansprüche

1. System (200), umfassend:

einen Generator (201), der dazu konfiguriert ist, Wechselstrom-, AC-, Spannung zu generieren; einen Leistungswandler (203), der dazu konfiguriert ist AC-Spannung in geregelte Gleichstrom-, DC-, Spannung zu wandeln; und einen Spannungsregler (205), der dazu konfiguriert ist, als eine Generatorsteuereinheit für den Generator (201) zu fungieren, der Spannungsregler (205) umfassend:

einen AC-Spannungsregler (351), der dazu konfiguriert ist, die AC-Spannung auf Basis einer AC-Ausgabe des Generators (201) zu regeln; einen DC-Spannungsregler (353), der dazu konfiguriert ist, die DC-Spannung auf Basis einer DC-Ausgabe des Leistungswandlers (203) zu regeln; und einen Regler-Wahlschalter (223), der dazu konfiguriert ist, den DC-Spannungsregler während des regulären Betriebs, in welchem die DC-Spannung für eine Last (213) bereitgestellt wird, auszuwählen, und den AC-Spannungsregler (351) auszuwählen, wenn mindestens eines aus einem Strom von dem Leistungswandler (203) und einer Spannung von dem Leistungswandler (203) mindestens eines aus einem lastfreien Zustand, einem Leichtlastzustand und einem Übergang anzeigt.

2. System (200) nach Anspruch 1, wobei der Regler-Wahlschalter (223) dazu konfiguriert ist, den AC-Spannungsregler (351) auf Basis eines detektierten lastfreien Zustands auszuwählen, wobei der Regler-Wahlschalter (223) dazu konfiguriert ist, den lastfreien Zustand auf Basis der Überwachung des Stroms von dem Leistungswandler (203) zu detektieren, wobei der Spannungsregler (205) dazu konfiguriert ist, die AC-Spannungen des Generators auf eine definierte Referenzspannung während eines Übergangs von einem Lastzustand zu mindestens einem aus einem lastfreien Zustand und einem Leichtlastzustand zu regeln.

3. System (200) nach Anspruch 1, wobei der Spannungsregler (205) einen Feldentladewiderstand (FDR) (221) beinhaltet und dazu konfiguriert ist, eine Steuerung eines dynamischen Bremswiderstands (DBR) (216) bereitzustellen, wobei ein Betrieb des DBR (216) zusätzlich durch DBR-Hardware (218) gesteuert wird und die DBR-Hardware (218) zunächst den Betrieb des DBR (217) bei Detektieren eines Entlastungsübergangs steuert, wobei die

Steuerung des DBR (217) von der DBR-Hardware (218) auf den Spannungsregler (205) übergeht.

4. System (200) nach Anspruch 1, ferner umfassend einen Hochspannungs-DC-Bus (212), wobei der Hochspannungs-DC-Bus (212) dazu konfiguriert ist, die DC-Spannung zur Verwendung durch eine oder mehrere Lasten (213) bereitzustellen.

5. System (200) nach Anspruch 1, wobei der Spannungsregler (205) eine Generatorsteuereinheit (325) ist.

6. Verfahren, umfassend:

Überwachen von Betriebszuständen eines Systems (200), das einen Generator (201), der AC-Spannung generiert, und einen Leistungswandler (203), der AC-Spannung in geregelte DC-Spannung wandelt, aufweist;
Ermitteln auf Basis eines Stroms des DC-Busses (212) und der DC-Spannung, ob der Leistungsgenerator (200) regulär in Betrieb ist, wobei der Leistungsgenerator (200) regulär in Betrieb ist, wenn er DC-Spannung für eine Last (213) bereitstellt;
im Falle des Ermittelns, dass der Leistungsgenerator (200) regulär in Betrieb ist, Auswählen einer DC-Spannungsregelung, um die DC-Spannung auf Basis einer DC-Ausgabe des Leistungswandlers (203) zu regeln;
im Falle des Ermittelns, dass der Leistungsgenerator (200) nicht regulär in Betrieb ist, durch Identifizieren auf Basis mindestens eines aus einem Strom von dem Leistungswandler (203) und einer Spannung von dem Leistungswandler (203), von mindestens einem aus einem lastfreien Zustand, einem Leichtlastzustand und einem Übergang,
Auswählen einer AC-Spannungsregelung, um die AC-Spannung auf Basis einer AC-Ausgabe des Generators (201) zu regeln; und
Steuern des Betriebs des Generators auf Basis der ausgewählten Spannungsregelung.

7. Verfahren nach Anspruch 6, wobei das Identifizieren des lastfreien Zustands auf Basis des Überwachens des Stroms des DC-Busses (212) erfolgt, wobei die AC-Spannungsregelung den Wert der AC-Spannung auf eine definierte Referenzspannung während eines Übergangs von einem Lastzustand in den lastfreien Zustand regelt.

8. Verfahren nach Anspruch 6, ferner umfassend das Steuern des Betriebs eines Feldentladewiderstands (FDR) (221) und eines dynamischen Bremswiderstands (DBR) (216).

9. Verfahren nach Anspruch 6, wobei eine Generatorsteuereinheit (325) ermittelt, ob der Leistungsgenerator (200) regulär in Betrieb ist.

Revendications

1. Système (200) comprenant :

un générateur (201) configuré pour générer une tension de courant alternatif, CA ;
un convertisseur de puissance (203) configuré pour convertir la tension CA en tension de courant continu, CC, régulée ; et
un régulateur de tension (205) configuré pour fonctionner comme une unité de commande de générateur pour le générateur (201), le régulateur de tension (205) comprenant :

un régulateur de tension CA (351) configuré pour réguler la tension CA sur la base d'une sortie CA du générateur (201) ;
un régulateur de tension CC (353) configuré pour réguler la tension CC sur la base d'une sortie CC du convertisseur de puissance (203) ; et
un sélecteur de régulateur (223) configuré pour sélectionner le régulateur de tension CC pendant un fonctionnement régulier dans lequel la tension CC est fournie à une charge (213), et pour sélectionner le régulateur de tension CA (351) lorsqu'au moins un d'un courant provenant du convertisseur de puissance (203) et d'une tension du convertisseur de puissance (203) indique au moins l'un d'un état hors charge, d'un état de faible charge et d'un transitoire.

2. Système (200) selon la revendication 1, dans lequel le sélecteur de régulateur (223) est configuré pour sélectionner le régulateur de tension CA (351) sur la base d'un état hors charge détecté, dans lequel le sélecteur de régulateur (223) est configuré pour détecter l'état hors charge sur la base d'une surveillance du courant provenant du convertisseur de puissance (203), dans lequel le régulateur de tension (205) est configuré pour réguler les tensions CA du générateur à une tension de référence définie pendant une transition d'un état de charge à au moins l'un de l'état hors charge et d'un état de faible charge.

3. Système (200) selon la revendication 1, dans lequel le régulateur de tension (205) inclut une résistance de décharge de champ (FDR) (221) et est configuré pour assurer la commande d'une résistance de coupure dynamique (DBR) (216), dans lequel le fonctionnement du DBR (216) est en outre commandé par le matériel DBR (218) et le matériel DBR (218)

commande initialement le fonctionnement du DBR (217) lors de la détection d'un transitoire de décharge, dans lequel la commande du DBR (217) passe du matériel DBR (218) au régulateur de tension (205).

4. Système (200) selon la revendication 1, comprenant en outre un bus CC haute tension (212), dans lequel le bus CC haute tension (212) est configuré pour fournir la tension CC destinée à être utilisée par une ou plusieurs charges (213).

5. Système (200) selon la revendication 1, dans lequel le régulateur de tension (205) est une unité de commande de générateur (325).

6. Procédé comprenant :

la surveillance des états de fonctionnement d'un système (200) ayant un générateur (201) qui génère une tension CA et un convertisseur de puissance (203) qui convertit la tension CA en tension CC régulée ;
le fait de déterminer si le générateur de puissance (200) fonctionne régulièrement sur la base d'un courant du bus CC (212) et de la tension CC, dans lequel le générateur de puissance (200) fonctionne régulièrement lors de la fourniture d'une tension CC à une charge (213) ;
lors de la détermination du fait que le générateur de puissance (200) fonctionne régulièrement, la sélection d'une régulation de tension CC pour réguler la tension CC sur la base d'une sortie CC du convertisseur de puissance (203) ;
lors de la détermination du fait que le générateur de puissance (200) ne fonctionne pas régulièrement en identifiant, sur la base d'au moins un courant provenant du convertisseur de puissance (203) et/ou d'une tension du convertisseur de puissance (203), au moins l'un d'un état hors charge, d'un état de faible charge et d'un transitoire, la sélection d'une régulation de tension CA pour réguler la tension CA sur la base d'une sortie CA du générateur (201) ; et
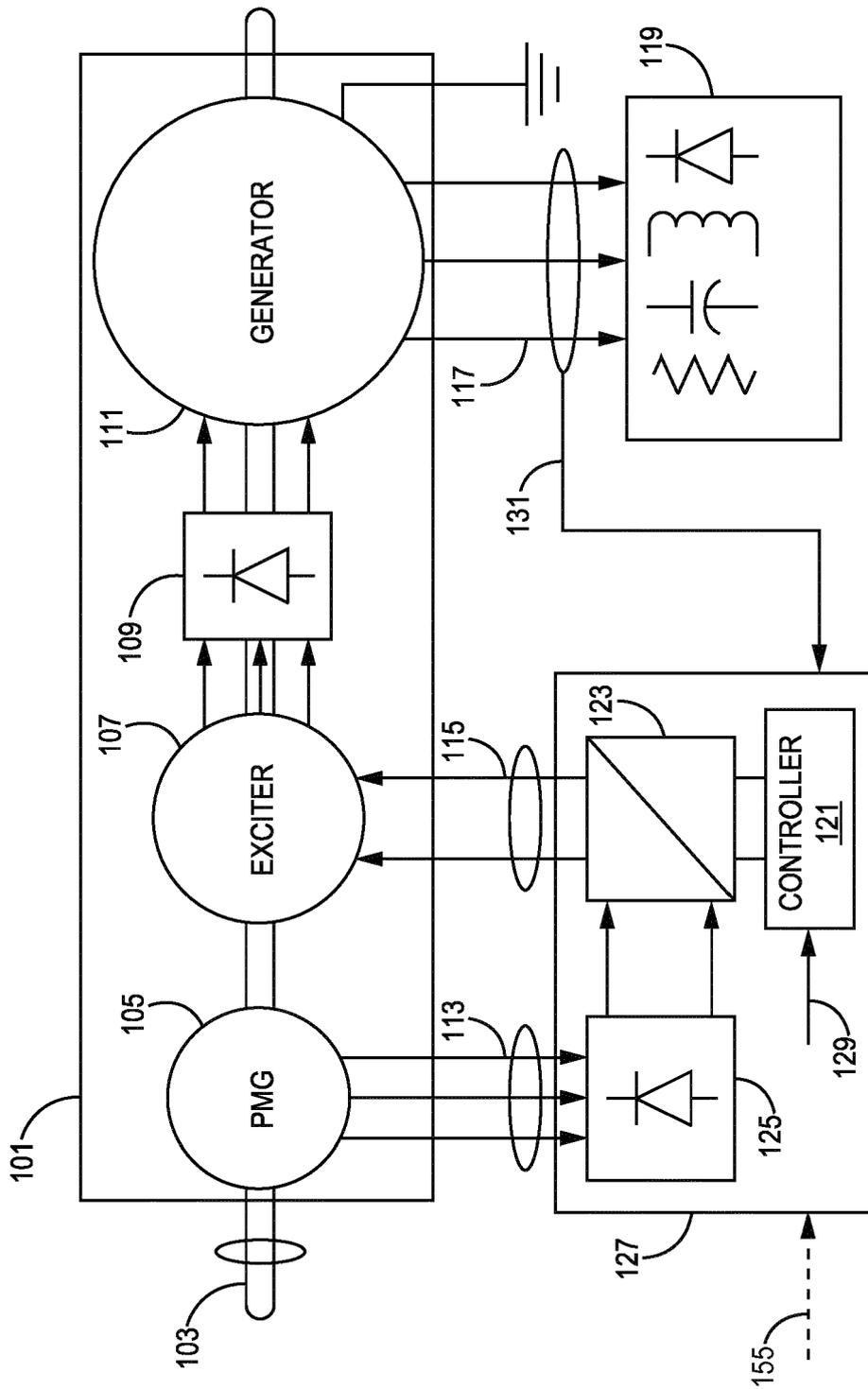la commande du fonctionnement du générateur sur la base de la régulation de tension sélectionnée.

7. Procédé selon la revendication 6, dans lequel l'identification de l'état hors charge est basée sur la surveillance du courant du bus CC (212), dans lequel la régulation de tension CA régule la valeur de la tension CA à une tension de référence définie pendant une transition d'un état de charge à l'état hors charge.
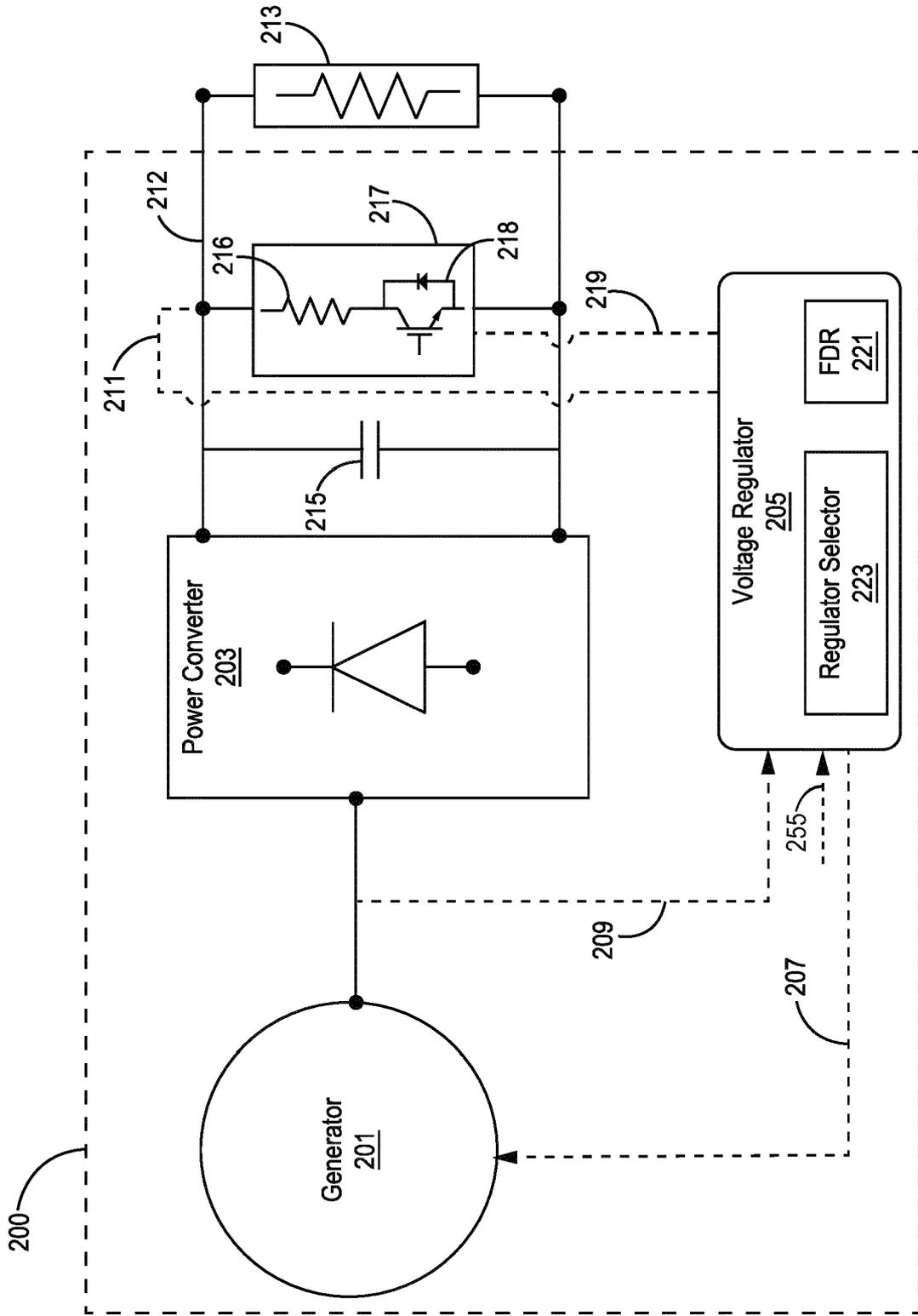
8. Procédé selon la revendication 6, comprenant en outre la commande du fonctionnement d'une résis-

tance de décharge de champ (FDR) (221) et d'une résistance de coupure dynamique (DBR) (216).

9. Procédé selon la revendication 6, dans lequel une unité de commande de générateur (325) détermine si le générateur de puissance (200) fonctionne régulièrement.
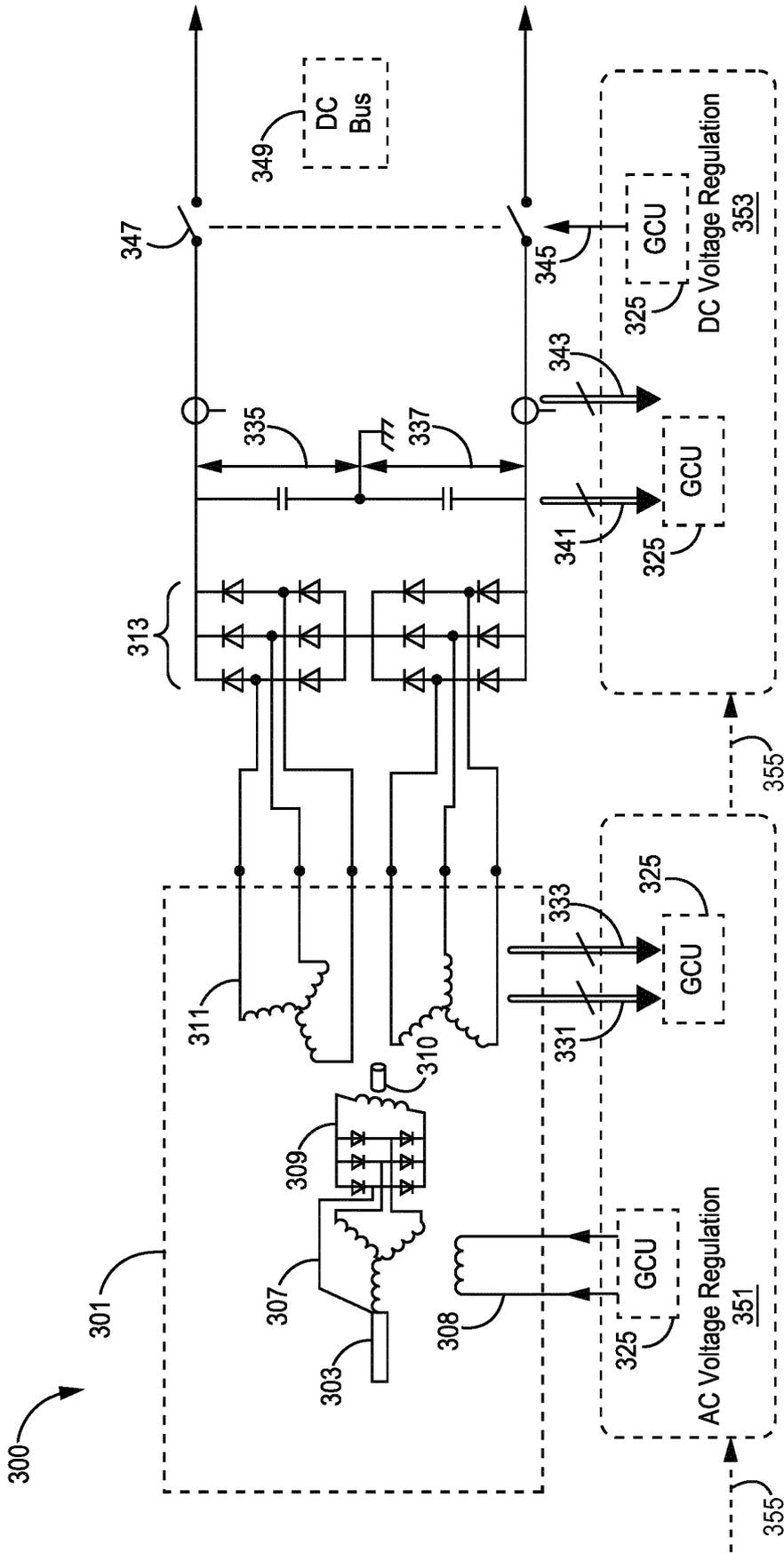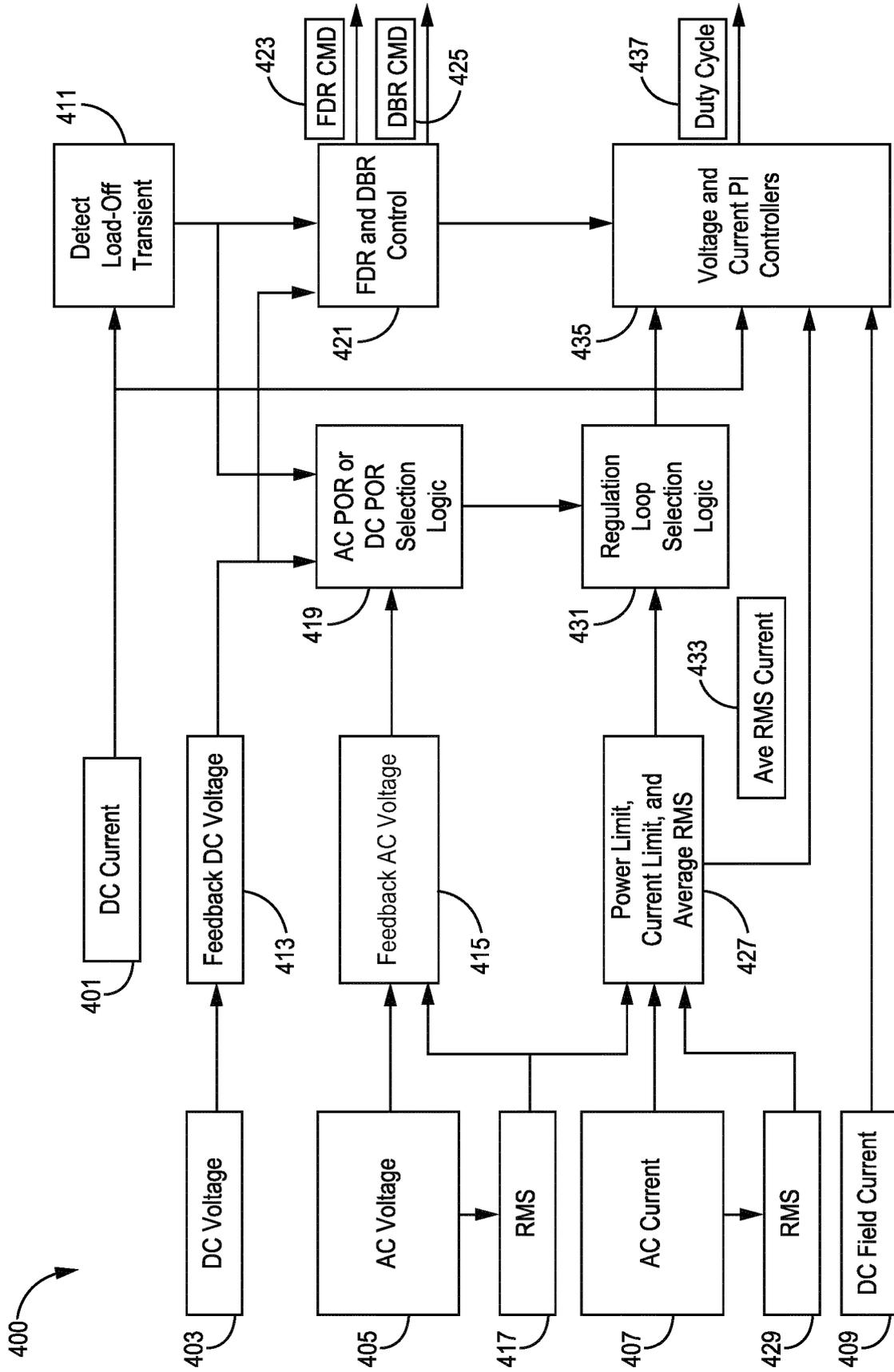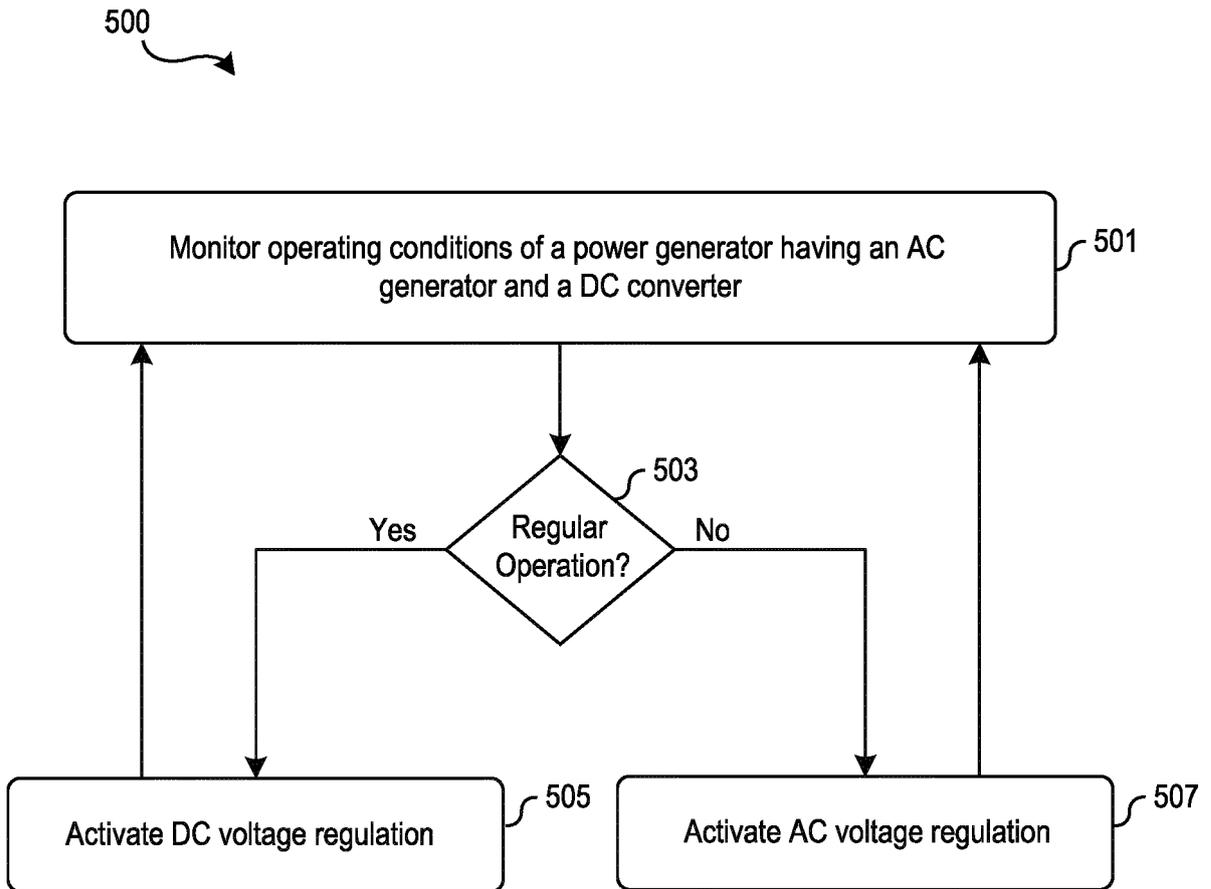
**FIG. 1
(PRIOR ART)**

FIG. 2

FIG. 3

FIG. 4

500

Monitor operating conditions of a power generator having an AC generator and a DC converter ⌐ 501

⌐ 503

Yes   Regular Operation?   No

Activate DC voltage regulation ⌐ 505

Activate AC voltage regulation ⌐ 507

FIG. 5

REFERENCES CITED IN THE DESCRIPTION

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